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HIGH VOLTAGE, HIGH POWER TRANSISTORS. CHARACTERISTICS OF DEVELO--ETC(U)

JAN 61  W M LAWSON

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Interim Report Number 8

Wilmer M. Lawson, Jr.

SOUND DIVISION

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(6) HIGH VOLTAGE, HIGH POWER TRANSISTORS.

Characteristics of Developmental Units.

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(10) by Wilmer M. Lawson, Jr.

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## ABSTRACT

The Radio Corporation of America, under the auspices of Office of Naval Research contract number NOBsr-81322, has continued development work on silicon power transistors. Eight state-of-the-art samples of this transistor, designated TA-1891, have been tested by the U. S. Naval Research Laboratory for voltage breakdown, output characteristics and saturation voltage.

The breakdown voltage of these units is in the range between 400 and 500 volts, and the characteristic is stable, with no negative resistance region up to 500 volts. Two units showed evidence of possible surface breakdown effects, ~~but~~ this could be an assembly problem relatively easily solved. Output characteristics, although satisfactory, should be improved, particularly at low collector voltages. Gain and saturation voltage for these ten ampere units are excellent. A fifty percent improvement in the gain would result in a 20 to 25 ampere unit. Thermal resistance could probably be improved, but is, on the average, adequate at this time for 300 watts dissipation. Two transistors are capable of 450 watts dissipation at 25°C case temperature, even in the interim case provided.

## PROBLEM AUTHORIZATION

ONR RF-001-03-41-4062, BUSHIPS 8134
NRL Problem Number 55S02-10

## PROBLEM STATUS

This is an interim report on one phase of the project; work on this problem is continuing.

## INTRODUCTION

Under the auspices of an Office of Naval Research contract, NOBsr 81322, the Semiconductor Products Division of the Radio Corporation of America has continued the development of silicon power transistors to meet the 300 volt, ten ampere, 200 watt requirement. The first complete, encased units on this contract of diffused-base, diffused-emitter design have been completed, and ten state-of-the-art units selected from approximately twenty-five that have been constructed and designated TA-1891 have been forwarded for testing. Of these ten, two were given to the Army Signal Corps Laboratory for testing, and eight have been given to the U. S. Naval Research Laboratory for tests.

The results of static tests on these units are herein enclosed. A class B amplifier test is yet to be run.

## BACKGROUND AND TEST PROCEDURES

The static characteristics which are obtained at NRL are the breakdown-voltage characteristics $V_{cbo}$, $V_{ces}$, and $V_{cep}$, the collector-output characteristic, and the saturation-voltage characteristic.

Voltage-breakdown characteristics are taken using a curve tracer described in NRL Memorandum Report 1098, High Voltage, High Power Transistors, Characteristics of Developmental Units, Report 5.

Basically, a half-wave, sixty-cycle, sine-wave voltage is applied in series with a current-limiting resistor and a current shunt to the proper transistor terminals for the characteristic being taken. The voltage and current are displayed on the calibrated x and y axes of an oscilloscope.

The collector-output characteristics are taken with the aid of the dual-transistor characteristic-curve tracer described in NRL Memorandum Report 834 and a calibrated oscilloscope. From the photographs of the output curves, the output impedance and forward current, gain may be calculated. Saturation-voltage characteristics are taken with the voltage, one-half wave, rectified sixty cycles per second sine-wave signal to the collector-emitter terminals of the transistor under test slightly after a large, fixed, dc bias current is applied to the base-emitter terminals.

The accuracy of these measurements is limited by the accuracy with which the data can be read from the photographs. Thus, values of

breakdown voltage, gain and saturation voltage quoted in this report cannot be compared rigorously to the data given by the manufacturer, but a good general description of the characteristics of the transistor is obtained.

## TEST RESULTS AND DISCUSSION

The results of the voltage-breakdown tests on the individual units are presented in figures 2 through 11 and in numerical form in table I. The manufacturer's data on the units is included as table II.

The final case and mounting methods are not yet determined, and all units are in an offset, single-ended case usually used in 70 watt germanium units. Despite this, it may be seen that, although leakage is somewhat large, the units have a breakdown voltage in all three modes of 400 volts minimum. The semiconductor design is apparently capable of 500 volts with leakage current still less than that required and without any trace of negative-resistance breakdown. Two of the units developed defects above 400 volts which are probably caused by surface contamination.

The output characteristics of the ten units are given in figures 12 to 20 and table I for a maximum base-bias of 100 ma, a collector supply of 50 to 60 volts peak and a 150 watt peak-power dissipation. ( Other base biases of 10 ma and 200 ma were used in figures 19 and 20.) No heat sink was used.

The current gain is sufficiently linear for use in power amplifiers; however, the gain at very low collector voltages is poor as the corners are quite rounded. The gain is 20-30 at one ampere collector current and five volts collector-to-emitter voltage. As ten ampere units, current gain at 20 and 30 amperes is excellent.

The saturation-voltage characteristics for a 2.5 volt base-to-emitter bias are given in figures 21 to 30. They generally agree with the manufacturer's data and are very small. The transistor is capable of 30 amperes insofar as the semiconductor properties are concerned.

## SUMMARY AND CONCLUSIONS

The breakdown voltages of these units are excellent; a minimum of 400 volts and usually 500 volts.

There is no evidence of instability whatever up to 400 volts; above 400 volts such instabilities that do occur are apparently surface defects and should be eliminated with further refinements in construction techniques.

There is no negative resistance breakdown up to 500 volts.

The output characteristics, although satisfactory for use, need improvement in the corners at low collector-to-emitter voltage where there is some fall-off of gain.

The current gain of these ten ampere units is satisfactory; in addition, the current gain remains quite high for collector currents to 30 amperes, instead of falling off.

It is probable that redesign of the emitter-comb structure will increase the current gain, allowing the use of this design as a 25 ampere unit.

The saturation voltage is excellent, being equal to or less than that usually seen in silicon transistors, particularly considering this as a ten ampere design.

These samples exhibit characteristics which are excellent for use in power amplifiers.

Thermal resistance, especially since the units were not furnished in the final case, is surprisingly good.

## [illegible]BLE I

### SUMMARY OF CHARACTERISTICS O[illegible] TA-1891 SILICON POWER TRANSISTOR AS MEASURED BY THE U. S. NAVAL RESEARCH LABORATORY[1]

| Transistor Number | $BV_{cbo}$(v) $I_c$ = 1 ma | $BV_{ces}$(v) $I_c$ = 5 ma | $BV_{ceo}$(v) $I_c$ = 10 ma | $h_{FE}$ $I_c$ = 1a $V_c$ = 5v | $h_{FE}$ $I_c$ = 3a $V_c$ = 10v | $V_{SAT}$ $I_c$ = 10a | $V_{SAT}$ $I_c$ = 20a |
|---|---|---|---|---|---|---|---|
| 58-3 | >500 | >500 | >500 | 23 | 28 | 0.40 | 0.7 |
| 61 | 205 | 400 | 495 | 20 | 27 | 0.40 | 0.8 |
| 64-1 | >500 | >500 | >500 | 20 | 24 at 2.4a | 0.35 | 0.6 |
| 65-1 | 145 | 440 | 475 | 33 | 31 | 0.30 | 0.6 |
| 65-3 | 405 | >500 | >500 | 39 | 40 | 0.40 | 0.9 |
| 70-1[2] | 200 | (2) | (2) | (2) | (2) | (2) | (2) |
| 70-2[3] | 310 | >480[3] | >480[3] | 24 | 27 at 2.7a | 0.30 | 0.6 |
| 70-6[4] | 350 | 440 | 100[4] | 24 | 25 at 2.5a<br>32 at 6.5a | 0.30 | 0.6<br>1.1 at 30a |

NOTES:

(1) All breakdown characteristics $V_{cbo}$, $V_{ces}$ and $V_{ceo}$ are almost identical.

(2) Broke down at 480 volts and did not recover. Probable surface defect.

(3) Exhibits instability above 400 volts. Possible start of surface breakdown.

(4) Broke down at 400 volts in $V_{ceo}$ test.

TABLE II

MANUFACTURER'S CHARACTERISTICS

RCA TA-1891 NPVN SILICON TRANSISTOR AT 25°C, MAXIMUM $T_J = 200°C$

| Unit Number | $BV_{cbo}$(v) at 1 ma | $BV_{ceo}$(v) at 5 ma | $BV_{ebo}$(v) at 5 ma | $I_{cbo}$(v) at 50v,μa | $h_{FE}$ 1a, 5v | $h_{FE}$ 5a, 10v | $h_{FE}$ 10a, 10v | $V_{CE}$(SAT)(v) 10a, $I_c$, 2a, $I_b$ | $F\alpha B$ (MC) | T.R. (°C/W) |
|---|---|---|---|---|---|---|---|---|---|---|
| 58-1[1] | 190 | >400 | 0.25 | 500 | 25 | 20.0 | 10.0 | 0.45 | Typical value at 20 ma and 6 volts > 10 mc | 0.35 |
| 58-3 | >400 | >400 | 3.00 | 40 | 27 | 20.0 | 8.3 | 0.45 | | 0.41 |
| 61 | 250 | >400 | 0.17 | 15 | 25 | 22.0 | 9.1 | 0.40 | | 0.42 |
| 64-1 | >400 | >400 | 0.40 | 50 | 24 | 15.4 | 6.0 | 0.60 | | 0.73 |
| 65-1 | 200 | >400 | 8.00 | 150 | 36 | 20.0 | 7.7 | 0.30 | | 0.50 |
| 65-3 | >400 | >400 | 11.00 | 200 | 50 | 28.0 | 8.3 | 0.32 | | 0.58 |
| 65-6[1] | 160 | >400 | 0.60 | 400 | 24 | 16.6 | 6.7 | 0.38 | | 0.37 |
| 70-1 | 220 | >400 | 0.30 | 130 | 21 | 18.0 | 7.2 | 0.35 | | 0.53 |
| 70-2 | 360 | >400 | 2.10 | 40 | 27 | 16.7 | 7.2 | 0.45 | | 0.46 |
| 70-6 | 420 | >400 | 11.00 | 65 | 27 | 14.5 | 6.2 | 0.55 | | 0.50 |

NOTE:

(1) Submitted to U. S. Army Signal Corps Laboratory

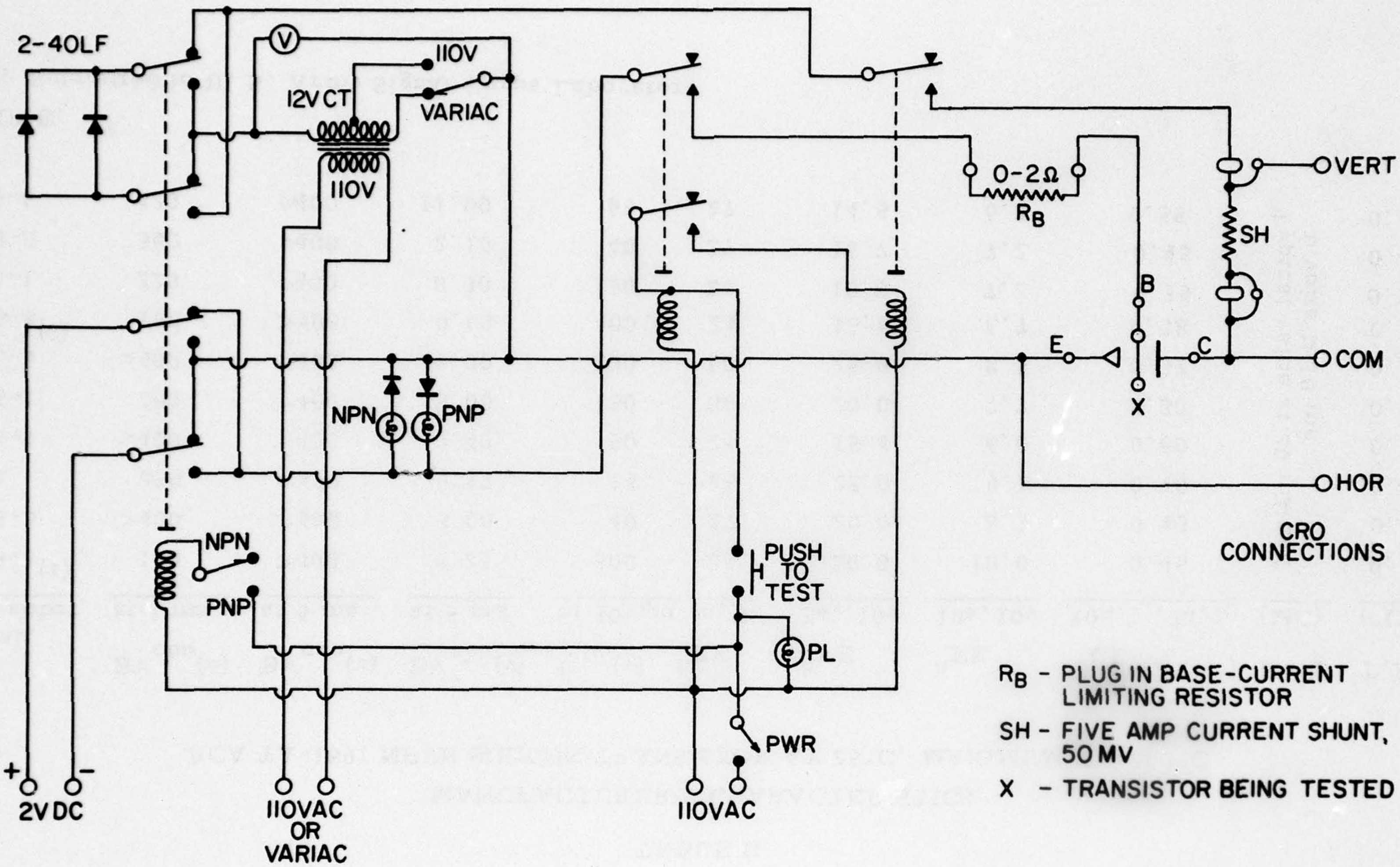


Fig. 1 - Common-emitter, saturation-voltage, characteristic-curve tracer

Fig. 2 - 58-3 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 3 - #61 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 4 - #61 (BV)

Hor. - 100v/div.
Vert. - 10 ma/div.

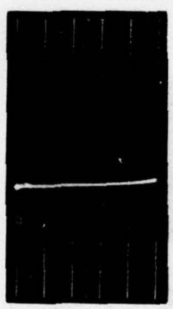

Fig. 5 - #64-1 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 6 - #65-1 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

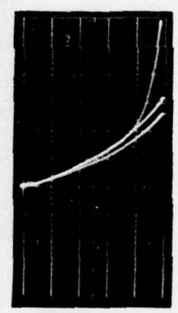

Fig. 7 - #65-1 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 8 - #65-3 (BV)

Hor. - 100v/div.
Vert. - 2 ma/ div.

Fig. 9 - #70-1 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 10 - #70-2 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 11 - #70-6 (BV)

Hor. - 100v/div.
Vert. - 2 ma/div.

Fig. 12 - #58-3 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

Fig. 13 - #61 (output)

Hor. 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

Fig. 14 - #64-1 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

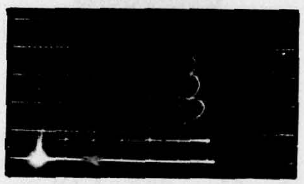

Fig. 15 - #65-1 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

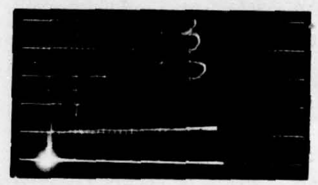

Fig. 15 - #65-3 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

Fig. 16 - #70-1 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

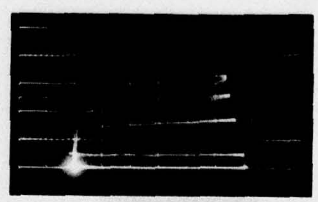

Fig. 17 - #70-2 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

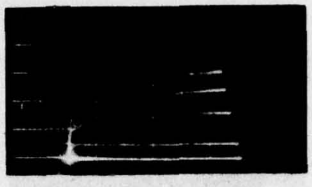

Fig. 18 - #70-6 (output)

Hor. - 10v/div.
Vert. - 1A/div.
Bias - 0, 25, 50, 75, 100 ma

Fig. 19 - #70-6 (output)

Hor. - 10v/div.
Vert. - 100 ma/div.
Bias - 0, 2.5, 5, 7.5, 10 ma

Fig. 20 - #70-6 (output)

Hor. - 10v/div.
Vert. - 2A/div.
Bias - 0, 50, 100, 150, 200 ma

Fig. 21 - #58-3 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

Fig. 22 - #61 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

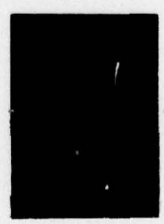

Fig. 23 - #64-1 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

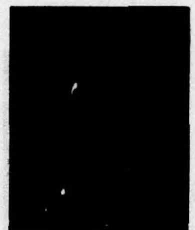

Fig. 24 - #65-1 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

Fig. 25 - #65-3 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

Fig. 26 - #70-1 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

Fig. 27 - #70-2 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

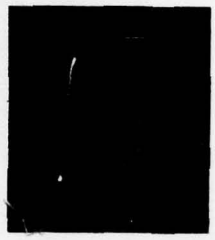

Fig. 28 - #70-6 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0.33 ohms

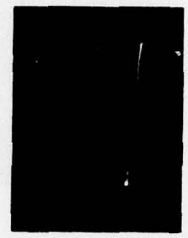

Fig. 29 - #70-6 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 5A/div.
Bias - 2.4v thru 0 ohms

Fig. 30 - #70-6 ($V_{sat}$)

Hor. - 2v/div.
Vert. - 10A/div.
Bias - 2.4v thru 0 ohms